

[54] REFLECTION OSCILLATORS EMPLOYING
SERIES RESONANT CRYSTALS⁷

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331/117 FE

[56] References Cited

U.S. PATENT DOCUMENTS

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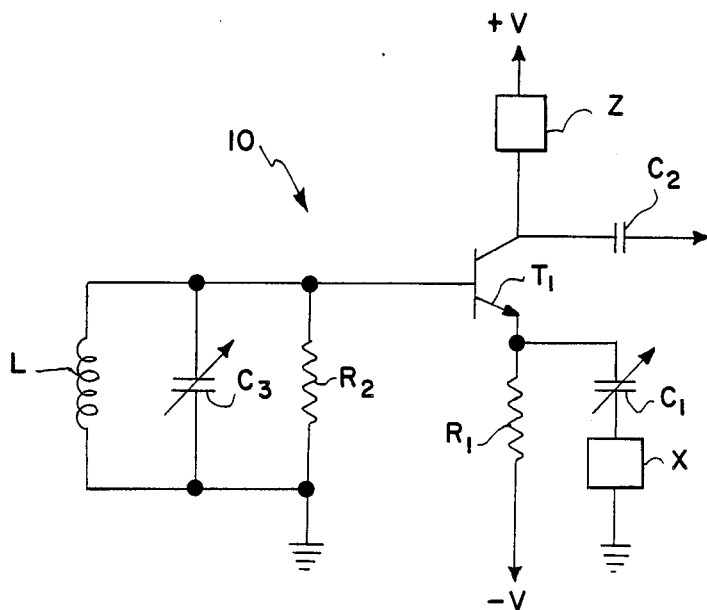
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[57] ABSTRACT

A reflection oscillator is provided which employs an active device operated in its roll-off region and two resonant circuits. For an oscillator employing a bipolar transistor, the emitter is connected to a series resonant capacitor-crystal network and the base is connected to an L-C tank circuit with the transistor being operated in the roll-off region of its gain versus frequency curve. This will provide a very high frequency of operation with a relatively inexpensive, low frequency, active device. These oscillators are easily tuned, stable, and require little d.c. power.

8 Claims, 2 Drawing Sheets



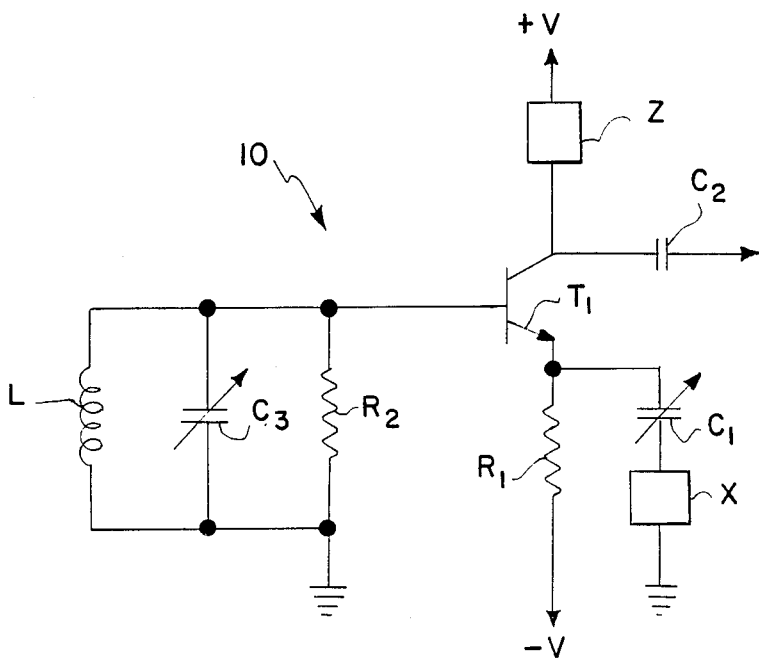


FIG. 1

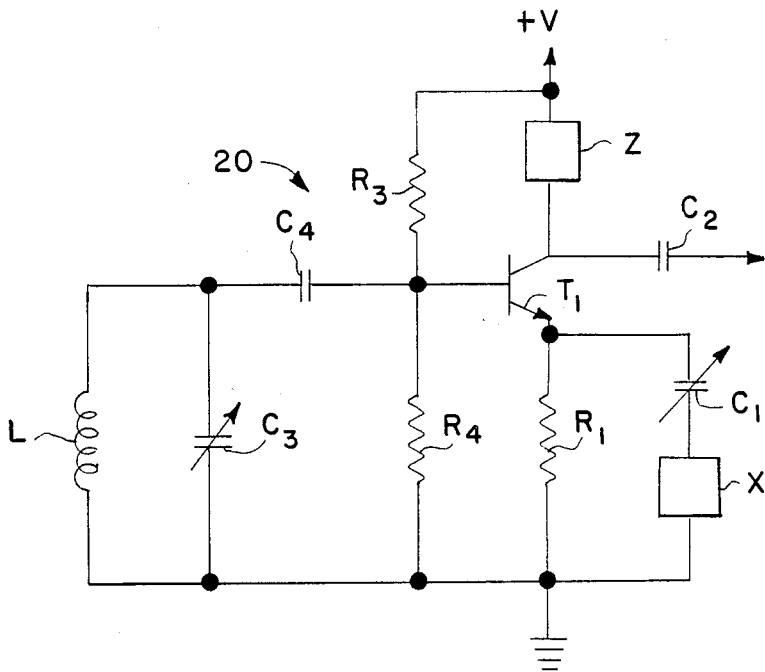


FIG. 2

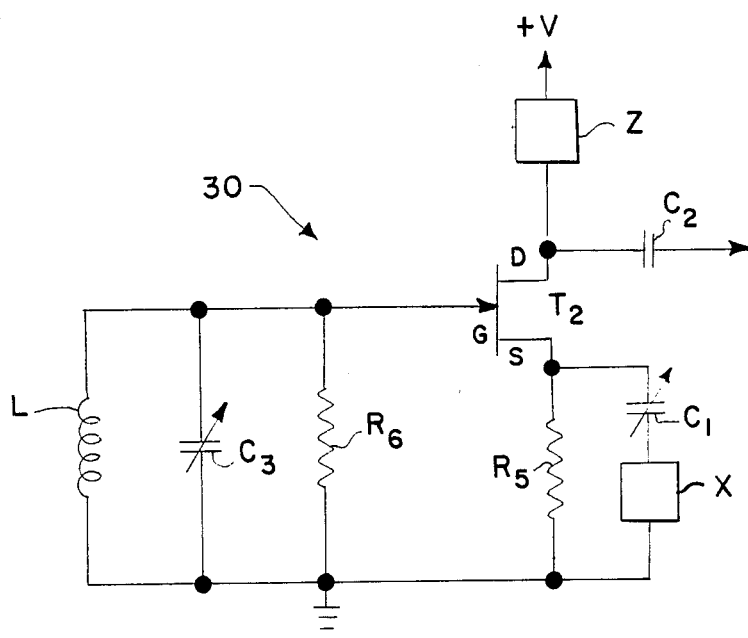


FIG. 3

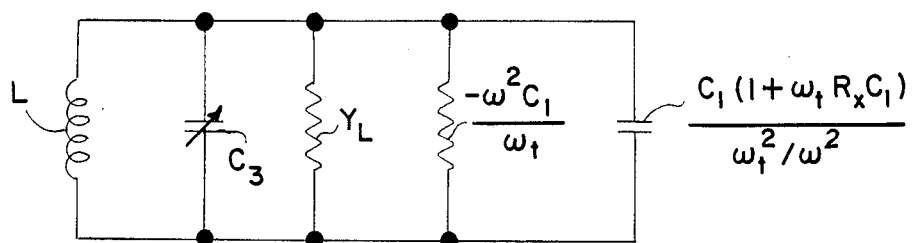


FIG. 4

REFLECTION OSCILLATORS EMPLOYING SERIES RESONANT CRYSTALS'

ORIGIN OF THE INVENTION

The invention described herein was made by an employee of the United State Government, and may be manufactured and used by or for the Government for governmental purposes without the payment of any royalties thereon or therefor.

TECHNICAL FIELD

This invention relates to oscillators, and, more particularly, to reflection oscillators.

BACKGROUND ART

Reflection oscillators have been employed since the introduction of solid state devices into the realm of circuit design. Devices such as impatts, trapatts, and tunnel diodes are two terminal devices that reflect a negative conductance across their terminals, and, when connected across a low loss resonant circuit, will sustain oscillations. Bipolar and field effect transistors obtain a negative conductance by inserting a reactance at one terminal and, through the transistor's gyrator characteristic, reflect a negative conductance at another terminal. The third terminal is employed as an output terminal. The negative conductance may sustain oscillations when connected across a low loss resonant circuit. Such oscillators are usually employed in the microwave region and are not crystal controlled. Currently, however, a fundamental or overtone crystal is commonly employed in a grounded base configuration of a Colpitts oscillator. For a given frequency, the transistor is operated in the flat portion of its gain versus frequency curve, which is considerably lower than F_r . This necessitates a relatively high frequency device, which is usually more costly. Alternatively, the F for such devices may be only increased by increasing the quiescent current.

Beyond 1 GHz, SAW resonators may extend the frequency range beyond the range of currently available crystals to 1.5 GHz. Beyond this frequency range, dielectric resonators (DRs) are now being employed up to 15 GHz. However, 15 GHz or 1.5 GHz SAW and DR oscillators have not achieved the stability of crystal oscillators. To achieve higher frequencies with crystal controlled oscillators, the current practice is to employ multipliers.

STATEMENT OF THE INVENTION

Accordingly, it is an object of this invention to provide a high frequency, stable oscillator.

It is another object of the invention to provide a high frequency, low power, low current oscillator.

It is yet another object of the invention to provide an inexpensive, high frequency oscillator.

It is still another of the invention to provide an easily tuned, high frequency oscillator.

Briefly, these and other objects are achieved in a crystal-controlled oscillator which includes a transistor operated in its roll-off region and a crystal operating as a series resonant component in series with a capacitor.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic representation of an oscillator, employing a bipolar transistor, in accordance with this invention.

FIG. 2 is a schematic representation of another oscillator employing a bipolar transistor, in accordance with this invention.

FIG. 3 is a schematic representation of another oscillator, employing a field effect transistor, in accordance with this invention.

FIG. 4 is an equivalent circuit which may represent this invention under certain conditions.

DETAILED DESCRIPTION OF THE INVENTION

Crystals have recently become available which are cut to operate at fundamental frequencies up to about 500 MHz and overtone frequencies up to about 1 GHz. The instant invention takes advantage of these high frequency crystals by providing reflection oscillators which include active devices operated well into their roll-off characteristic. In the case of a bipolar transistor, the transistor is operated well beyond its 3 db down point on its current gain versus frequency curve. For field effect transistors, the transistor is operated well beyond its 3 db down point on its transconductance versus frequency curve.

These circuits employ a crystal operating as a series resonant component in series with a capacitor. For the bipolar transistor circuit, the series capacitor-crystal network is in the emitter while for a field effect transistor, the series capacitor-crystal network is in the source. The crystal, in the bipolar transistor configuration, provides, ideally, a series resistance in series with a capacitor in the emitter circuit which modifies the negative conductance reflected across the base by the series capacitance so that, at the resonant frequency, the maximum negative conductance is reflected. These circuits provide relatively low power designs using relatively low cost active components. The circuits are additionally cost effective in terms of employing a minimum number of parts with attendant low labor costs for construction and testing.

Referring now to the drawings wherein like reference numerals and characters designate identical or corresponding parts throughout the figures, and more particularly to FIG. 1 wherein a reflection oscillator 10 is illustrated. This oscillator is shown as including a single bipolar transistor T_1 as its sole active element. A 2N930 transistor was chosen for this embodiment because it has a comparatively high frequency characteristic and it is relatively inexpensive. The emitter of transistor T_1 is connected to a variable capacitor C_1 , which may be in the range of 3 to 15 pf, in series with a 25 MHz third overtone crystal X which is connected to ground. The emitter is also connected to resistor R_1 , which may be 4.3 K Ω , which is in parallel with the capacitor C_1 —crystal series network and is connected to $-V$, which may be a -5 volt power supply. The collector of transistor T_1 is connected to an impedance Z which is, in turn, connected to $+V$, which may be a $+5$ volt power supply. Impedance Z may be any relatively small impedance, such as a 220 Ω resistor, from which an output signal may be extracted. It may also be a parallel L-C network which will not have any significant resistive loss and will aid in signal filtering. It may also be a more detailed matching network, such as an

"L" section. An a.c. coupling capacitor, C_2 , which may be in the order of $0.01 \mu\text{f}$, may be connected to the transistor collector. The base of transistor T_1 is connected to a parallel network comprised of L , C_3 , and R_2 , which may be a $1 \mu\text{h}$ inductor, an adjustable capacitor set to about 20 pf and a $20 \text{ K}\Omega$ resistor, respectively. R_2 is employed to set the negative conductance equal to a positive conductance at the frequency of interest. In the circuit configuration of FIG. 1, therefore, the base sees a d.c. ground and the emitter will be about -0.7 volts due to the forward biased, base to emitter, diode voltage drop. Accordingly, the circuit will be biased by the voltage across R_1 , i.e., about 4.3 volts across the $4.3 \text{ K}\Omega$ resistance. Accordingly, the emitter will be about center biased and the collector and emitter will draw about 1 ma .

FIG. 2 depicts reflection oscillator 20 which is an equivalent of oscillator 10. The components are the same except that a R_2 is eliminated and, R_3 , R_4 and C_4 are added in order that a single power supply, $+V$, may be employed. R_3 , R_4 , C_4 and $+V$ may be $39 \text{ K}\Omega$, $39 \text{ K}\Omega$, $0.001 \mu\text{fd}$ and $+10$ volts, respectively. R_3 and R_4 set the d.c. bias while C_4 provides a d.c. block which is not necessary in the FIG. 1 circuit because the base is operated at ground potential.

Because R_3 and R_4 have the same magnitude of resistance, they will approximately center bias the emitter between $+V$ and ground. Their equivalent shunt impedance, as seen from the base, will approximate the $20 \text{ K}\Omega$ resistance of R_2 in FIG. 1. Accordingly, the functional equivalency of the circuits of FIG. 1 and FIG. 2 should be apparent.

FIG. 1 and FIG. 2 also operate similarly. Crystal X sets the oscillator frequency. If Z is a tuned circuit, Z is tuned to the crystal frequency. The C_1 , X network is reflected to the base and appears, in essence, as a capacitance, resistance and a negative resistance, all of which are in parallel with the L , C_3 and R_2 (or the R_3 , R_4 equivalent). The negative resistance is an essential requirement for oscillation to occur. The L , C_3 tuned circuit must be tuned somewhat higher than the crystal frequency because of the reflected capacitance, i.e., the L , C_3 circuit must be somewhat inductive for the reflected capacitance to tune this tuned circuit to the crystal frequency.

FIG. 3 depicts a reflection oscillator circuit 30, employing a field effect transistor (FET) T_2 , which circuit is, in essence, a functional equivalent of circuits 10 and 20. Field effect transistor T_2 may be an N- or P-channel type, the requirement only being that it have a high transconductance, g_m . Its drain D is connected to impedance Z , which may be either resistive or tuned, as in the previously described circuits and which is also connected to a.c. coupling capacitor C_2 . Impedance Z is, in turn, connected to a power supply, $+V$, which may be about $+10$ volts. The source connection of transistor T_2 is connected to ground through resistor R_5 , which may be about $2.2 \text{ K}\Omega$, and is also connected to ground through a series variable C_1 , crystal network in parallel with resistor R_5 . The gate connection is connected to ground both through resistor R_6 as well as through inductor L , both of which provide a d.c. path for the gate. The magnitude of R_6 is related not to the biasing but to the reflected $-R$ and the conditions for oscillation. The FET is essentially self-biased in a linear region. Resistor in conjunction with R_6 , sets the transconductance of the FET. For this circuit to operate, g_m^{-1} must be small compared to the reactance of C_1 . It should be

noted that inductor L may be one winding of a transformer with the other winding connected to the load. This is also true for circuits 10 and 20.

It should be emphasized that the transistors employed in circuits 10, 20 and 30 are operated at about one-half the transistor frequency F_t , which is considerably higher than the 3 db frequency of the device operated, for instance, in the case of the bipolar transistor, in the grounded emitter configuration. The operation of these circuits can be analyzed as follows. For the bipolar transistor circuits, the input admittance at the base of transistor T_1 due to the series combination of crystal X and capacitor C_1 is given by:

$$Y_{in} = \frac{(1 + j\omega_r/\omega)}{1 + (\omega_r/\omega)^2} \times \frac{1}{(R + 1/j\omega C)} \quad (1)$$

where R_x is the series resistance of the crystal at resonance and ω_r is the transitional radian frequency of T_1 .

Performing an algebraic manipulation on equation (1) we obtain:

$$Y_{in} = \frac{(\omega^2 C_1^2 R_x - \omega_r C_1) + j\omega C_1 (1 + \omega_r C_1 R_x)}{[1 + (\omega_r^2/\omega^2)] \times (1 + \omega^2 C_1^2 R_x^2)} \quad (2)$$

Equation (2) has excluded the effects of resistor R_1 as it is significantly larger in magnitude than the C_1 , X series network. Also, the emitter impedance is discounted as it is small in comparison with said series network.

A coarse approximation of equation (2) is:

$$Y_{in} = -\omega^2 C_1/\omega_r + \omega^2/\omega_r^2 X j\omega C_1(1 + \omega_r C_1 R_x) \quad (3)$$

Thus, the C_1 , X network in the emitter of transistor T_1 reflects as a negative conductance in parallel with a capacitive susceptance, as given by equation (3).

FIG. 4 depicts an equivalent circuit that is useful in analyzing the conditions of oscillation. The conditions of oscillation are given by the following equations 4 and 5 employing the parameters set forth in FIG. 4, which equations represent the separation of equation 3 into its real and imaginary parts:

$$1/j\omega L + j\omega C_3 + j\omega C_1 (1 + \omega_r R_x C_1) \omega^2/\omega_r^2 = 0 \quad (4)$$

$$Y_L - \omega^2 C_1/\omega_r = 0, \quad (5)$$

where Y_L represents the admittance related to the total losses in the base circuit of T_1 , which includes both the coil losses as well as the losses due to R_2 .

An approximate solution of equation (4) is:

$$\omega^2 = 1/L(C_3 + C_1/4) \quad (6)$$

This is useful in determining the approximate frequency of operation and the major elements which determine that frequency. The analysis for FETs is similar; only the parameters and values are different.

What has been described is an invention which includes reflection oscillator circuits which can operate at high frequencies while employing relatively low frequency, inexpensive active components which do not require high gain-bandwidths or high current operation. These circuits require little d.c. power and are suitable for use in integrated circuits. The crystals provide the negative resistance required for oscillation over a very

easily tuned, narrow and selective range, as well as frequency stability.

I claim:

1. A reflection oscillator including an active device with at least two terminals operated in its roll-off region and further including two tuned circuits, one of which is connected to one terminal of said device and the other of which is connected to another terminal of said device.

2. The reflection oscillator of claim 1 wherein said one tuned circuit includes a series resonant crystal.

3. The reflection oscillator of claim 1 wherein said other tuned circuit includes a lumped constant L-C resonant circuit.

4. The reflection oscillator of claim 2 wherein said crystal is the fundamental frequency setting element of said oscillator.

5. A reflection oscillator including a bipolar transistor operated on the roll-off region of its gain versus fre-

quency curve and further including two tuned circuits, one of which is a series resonant, capacitance, crystal network connected to said transistor's emitter and the other is a lumped constant, L-C resonant circuit connected to said transistor's base.

6. The reflection oscillator of claim 5 wherein an impedance is connected to said transistor's collector and the output of said oscillator is taken from said collector.

7. A reflection oscillator including a field effect transistor operated on the roll-off region of its transconductance versus frequency curve and further including two tuned circuits, one of which is a series resonant, capacitance, crystal network connected to said transistor's source and the other is a lumped constant, L-C resonant circuit connected to said transistor's gate.

8. The reflection oscillator of claim 7 wherein an impedance is connected to said transistor's drain and the output of said oscillator is taken from said drain.

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